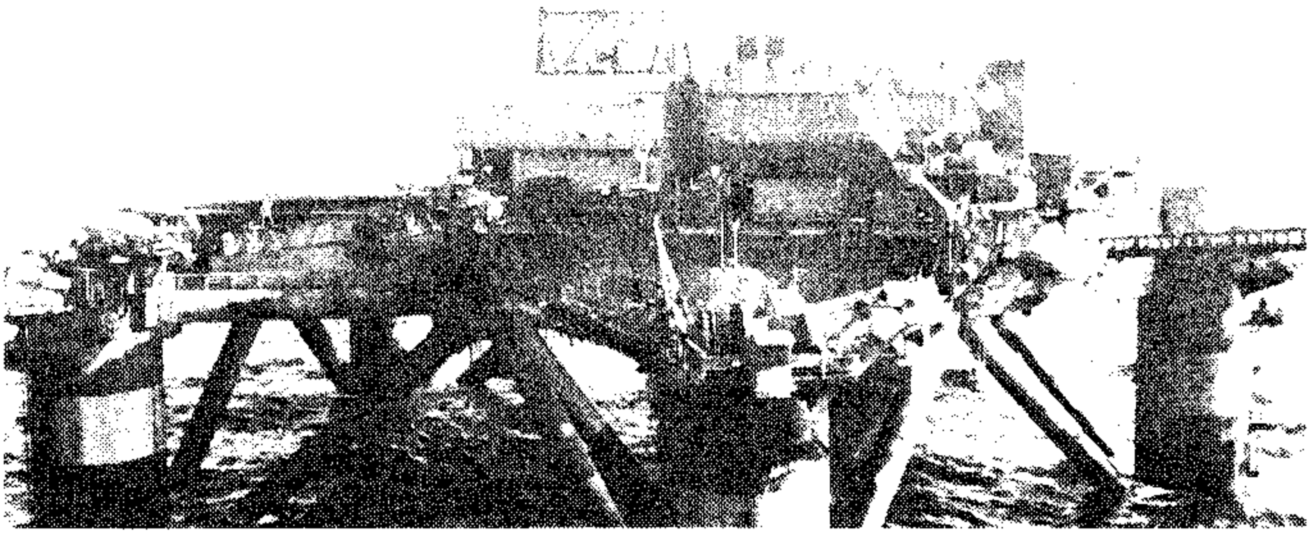
The Alexander L. Kielland Accident

Proceedings from
The First Robert Bruce Wallace Lecture
Department of Ocean Engineering
Massachusetts Institute of Technology

Contents



Proceedings from
The First Robert Bruce Wallace Lecture
Department of Ocean Engineering
Massachusetts Institute of Technology

Lecturer
Professor Torgeir Moan
The Norwegian Institute of Technology
Trondheim

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The lecture has been established by a gift from Mr. and Mrs. A. H. Chatfield to bring advanced ideas in ocean engineering to the MIT community and the public. Mrs. Chatfield is the daughter of Robert Bruce Wallace '98. Mr. Wallace was president of the American Ship Building Company and made major contributions to the development of inland waterways shipping.

Each spring the lecture will be part of a program in which MIT's faculty and students can meet with an eminent figure in the marine field to discuss attendant opportunities and problems of technology development for ocean uses. A lecturer, chosen by the MIT Department of Ocean Engineering, will present a paper to the MIT community and the public. For the balance of the week, informal seminars will allow an exchange of ideas on the lecture topic and on a broad range of mutual interests.

Dr. Torgeir Moan, professor of marine structures at the Norwegian Institute of Technology, Trondheim, was the first Robert Bruce Wallace lecturer. Professor Moan is an engineering expert and the author of numerous papers on fatigue of offshore structures and design directions for safety. He recently served as a member of the Norwegian Royal Commission which investigated the March 1980 collapse of the North Sea oil rig, the *Alexander L. Kielland*, a catastrophic accident which resulted in 123 deaths. Professor Moan's lecture presented the Royal Commission's findings for the first time to a United States audience.

The MIT Sea Grant College Program has joined with the MIT Department of Ocean Engineering to publish the proceedings from the First Robert Bruce Wallace Lecture to further the broad dissemination of a detailed examination of this tragic accident. The lessons learned have important implications for the management of offshore development worldwide.

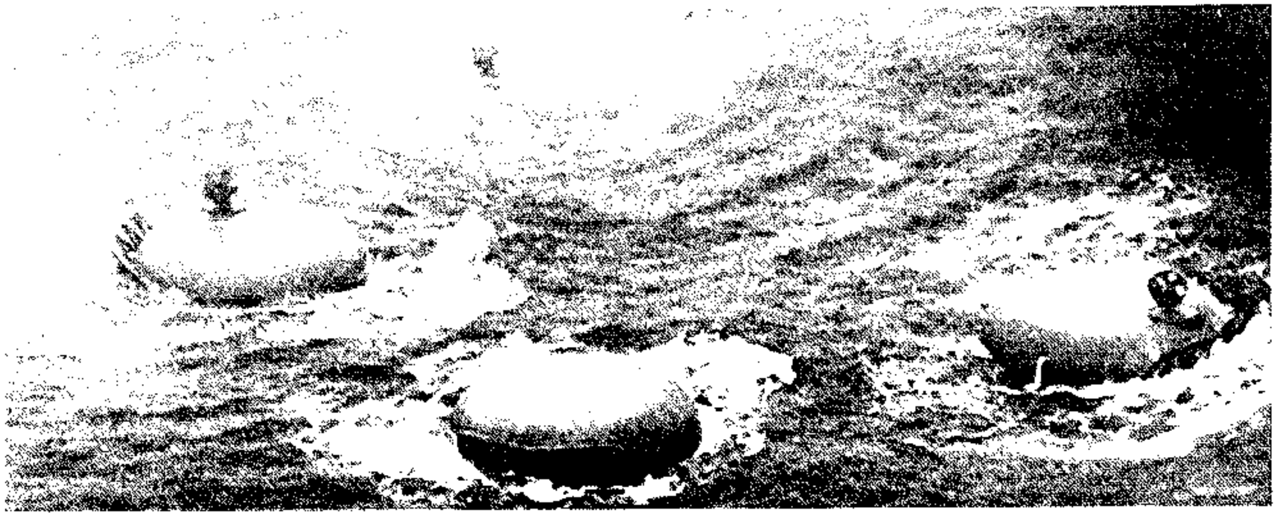


Figure 1
The *Alexander L. Kielland* after the accident.

On March 27, 1980 at about 6:30 pm, one of five columns broke off the hotel platform the *Alexander L. Kielland*. The platform heeled over. When flooding of the buoyancy chambers started, the platform continued to heel and sink. After about 20 minutes, it capsized. See Figure 1. Out of the 212 men on board, 123 lost their lives.

On March 28, 1980 the Norwegian Government, through a Royal Decree, and according to the Norwegian Maritime Law, Paragraph 314, set up an inquiry commission. The following men were appointed to serve:

Thor Naesheim, Chairman
District Judge
Sandnes

Torgeir Moan
Professor at the Norwegian Institute of Technology
Division of Marine Structures
Trondheim

Per Bekkvik
Platform Manager, Captain
Arendal

Aksel Kloster
Secretary at the time of appointment,
later local community enterprise manager
Stord

Sivert Oeveraas
Director
Norwegian Shipowners' Association
Oslo

The mandate given the Commission was to investigate the causes of the accident. Further, the Commission was asked to evaluate how the lifesaving appliances and the evacuation and rescue procedures operated during the accident. They were asked to recommend changes to help correct the identified inadequacies.

The Commission investigated the broken platform column, column D, as soon as it was towed to shore. When the lifeboats and other parts of the lifesaving appliances were found and brought on shore they, too, were examined. The Commission had samples cut from the D-6 bracing, which remained on the *Alexander L. Kielland*, and sent them to two laboratories for investigation and material testing. The investigations undertaken included, among other things, chemical, mechanical and metallographic analysis, and fracture surface studies. In addition, the Commission asked different specialists to carry out hydrodynamic, strength and stability calculations, and an analysis of the anchoring system. Experts also assisted the Commission in registering and surveying the lifesaving appliances brought ashore.

The Commission took testimony from 117 witnesses and had at its disposal other transcripts, as well as documents and pertinent information from police hearings, which were being held simultaneously with the Commission investigation. Finally, the Commission obtained a number of documents, such as drawings of the rig, letters of approval, certificates, and survey reports which related to the *Alexander L. Kielland* and the accident.

The Commission's findings are summarized in this lecture.

SECTION A - A

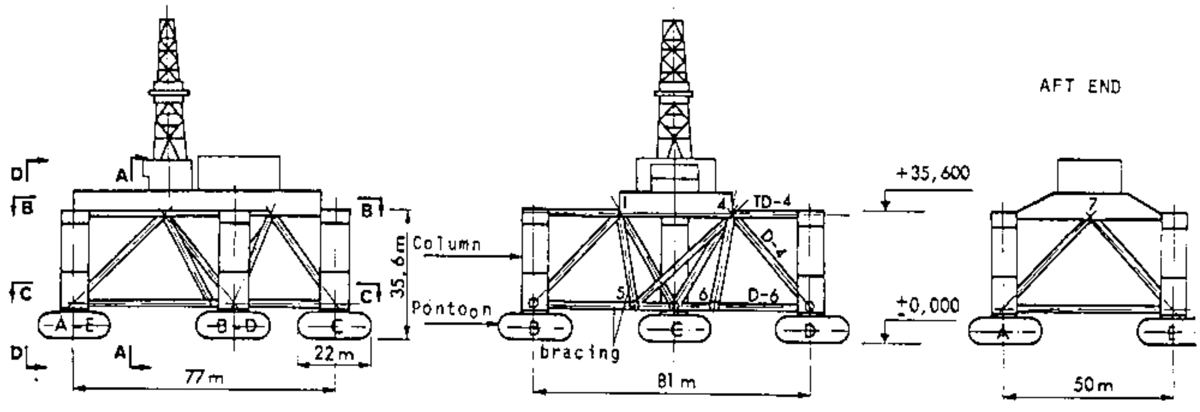
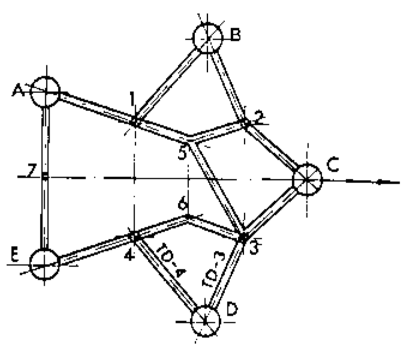
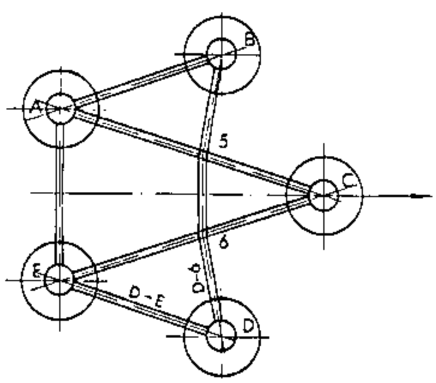


Figure 2
General layout of the *Alexander L. Kielland*.

SECTION B - B



SECTION C - C



The *Alexander L. Kielland* is a mobile platform of the pentagone type developed in France in 1965-70. As shown in Figure 2, the platform consisted of five pontoons (columns) which made up the major buoyancy elements. The columns and the deck on the top were supported by bracings. Figure 3a shows the starboard side of the platform with the location of the hydrophone, a positioning instrument, on bracing D-6. The hydrophone support was fixed to the bracing by inner and outer fillet welds, as shown in Figure 3b. The platform was constructed in France after a contract was signed at the end of 1973 by a French yard and the Norwegian owners. Figure 4 shows the platform under assembly. The *Alexander L. Kielland,* the ninth of the pentagone designs to be fabricated, was delivered to the owners on July 5, 1976.

It was built as a drilling rig, but was always utilized as an accommodation platform. The original capacity of 80 beds had been increased in four renovations in which new accommodation containers were mounted on the deck, forward of the drilling tower. When the last addition was made in March/April 1978, the platform could accommodate 348 beds.

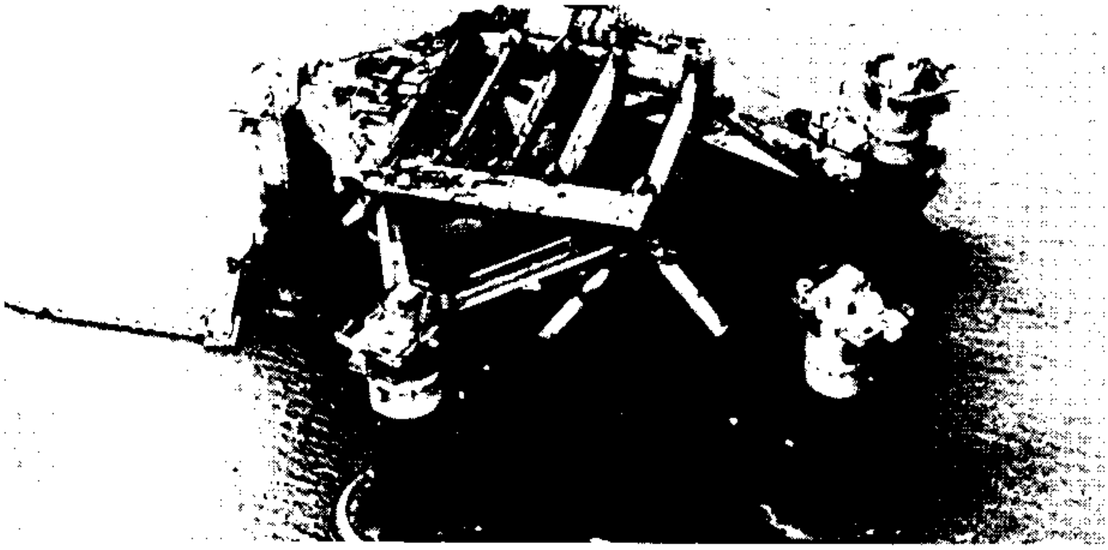


Figure 4
The *Alexander L. Kielland* during construction in Dunkerque. The deck is partially mounted.

The *Alexander L. Kielland* was equipped with certificates as required by regulations issued by the Norwegian Maritime Directorate and was classified with Det norske Veritas. The Maritime Directorate, as well as Det norske Veritas, surveyed the rig during construction and operation, using existing rules and regulations. The inspections revealed only small, and comparatively insignificant, defects.

The valid rules and regulations did not include requirements on residual strength following structural damage. However, damage stability requirements existed and had been applied. They did not account for the severity of damage experienced by the *Alexander L. Kielland* with the loss of column D. Existing rules required, as they do now, only that the rig remain afloat in a stable position after flooding of up to two adjacent tanks in a column. Watertightness was only required for the doors on top of the columns. This was the case because original stability calculations for the platform indicated that the deck would not be submerged by damage to the structure. This is directly connected to the fact that, according to current rules, loss of a column was not considered at the planning stage. The designer had allowed for water- and weathertightness of the hull by giving the deck ample strength to withstand water pressure. However, the specifications for the closing did not use a corresponding standard. To a large extent, the deficiency was remedied by the builders who worked out specification requirements on the tightness of the closing appliances. This meant that especially the lower part of the deck was designed so the platform could remain floating for a long time when closing appliances were shut. In addition, the operational manual included requirements for tightening doors and ventilators on the columns during operation. The same applied to manhole covers, such as those in oblique bracings, upper horizontal bracings, and upper nodes. In bad weather, doors on outside transverse bulkheads in the deck were also to be closed.

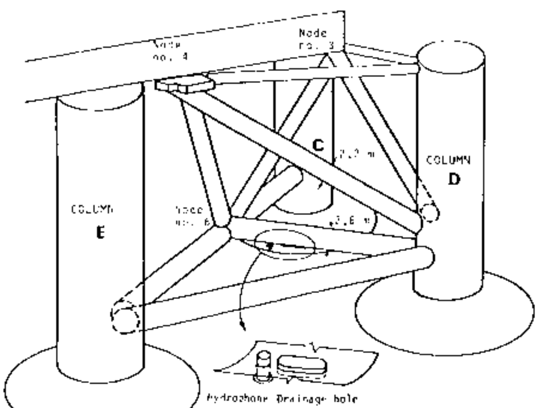


Figure 3a
Location of the hydrophone on bracing D-6 of the *Alexander L. Kielland*.

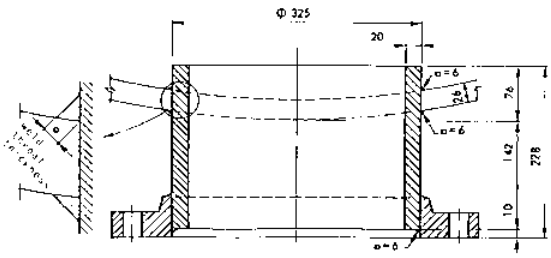


Figure 3b
Hydrophone support on the bracing D-6 of the *Alexander L. Kielland*.

Figure 6
Pontoon - column D with a part of the bracing D-6. Cracks in the bracing and the joint between the hydrophone support and the bracing.

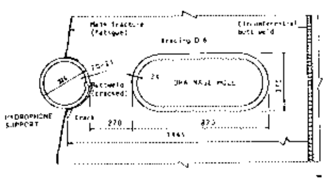


Figure 9
Fracture surface of the hydrophone support on the bracing D-6.

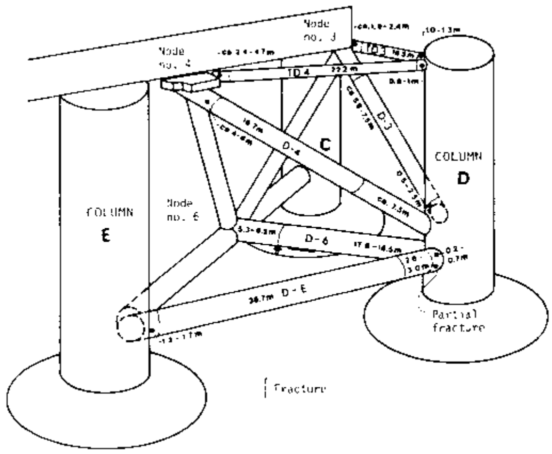


Figure 5
Location of fractures in the bracings of the *Alexander L. Kielland*.

On March 27, 1980, the day of the accident, the *Alexander L. Kielland* lay at anchor in the Ekofisk field, close to the production platform Edda 2/7C. Its position had been nearly the same during the previous nine months. Because of bad weather, poor visibility, a wind velocity of about 16 to 20 meters per second, and wave heights of about 6 to 10 meters, the platform was shifted somewhat away from Edda 2/7C in the afternoon. The gangway which connected the two platforms was hoisted on board the *Alexander L. Kielland*. About half an hour later, a few minutes before 6:30 pm, column D broke off.

Technical-Physical Accident Chain

First, bracing D-6 broke off. Then, in rapid succession, the five other bracings, which connected column D to the platform, failed from overloading. Figure 5 shows the approximate location of the fractures. Figure 6 illustrates the features of the fractures in the D-6 bracing.

The fracture in bracing D-6, which initiated the structural failure, was caused by fatigue. Figure 7 displays a sketch of the most significant macroscopic features of the fracture surface. The so-called stop-lines, which are typical for a fatigue failure, show where the crack front had stopped, or progressed slowly, at different times. It is noted that the hydrophone support is located in the fracture cross section. The hydrophone support tube was joined to the bracing by two fillet welds. Fractures had also occurred in, and adjacent to, these welds over most of the circumference of each. See Figures 8 and 9.

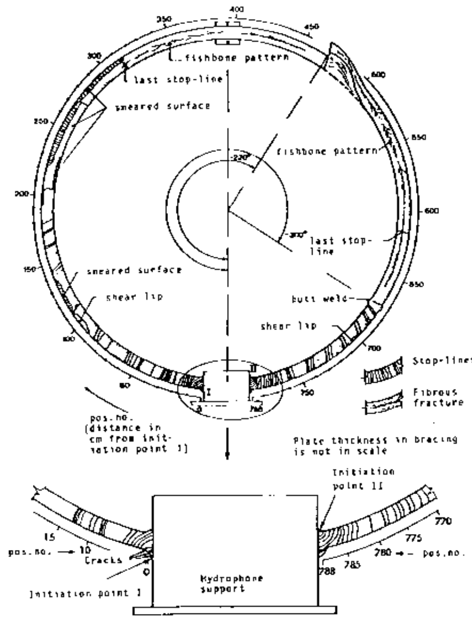


Figure 7
Sketch of the fracture surface of bracing D-6.

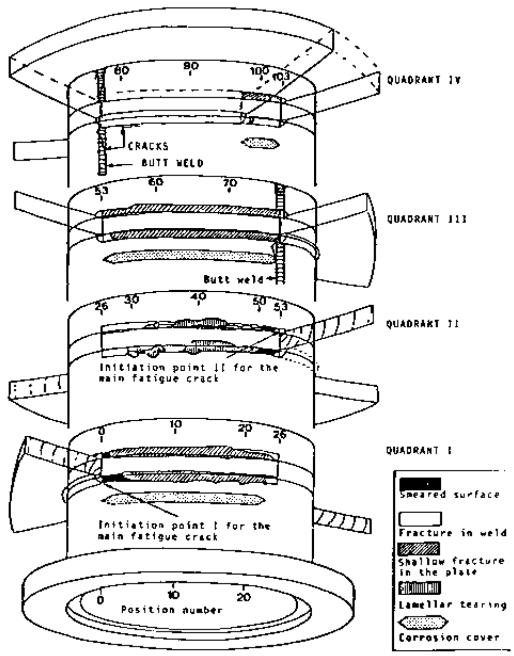


Figure 8
Sketch of the fracture surface of the joints between the hydrophone support and the bracing.

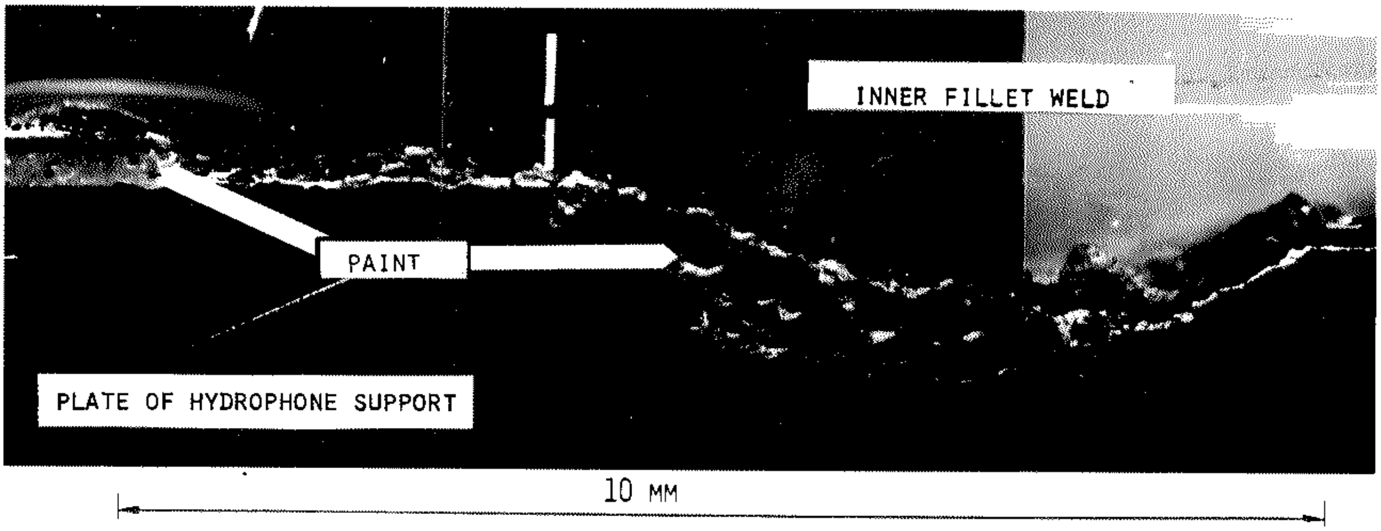


Figure 10
Longitudinal cross-section of the plate of the hydrophone support. Paint on the fracture surface.

Investigations after the accident revealed a less than satisfactory shape for the fillet weld beads. At the same time, penetration through the hydrophone support plate was rather small. Low strength and ductility in the direction of the plate thickness of the steel material and inferior quality of the fillet welds, together with a high stress level in the welds, resulted in fractures in the welded connection between the hydrophone support and the bracing, and in the hydrophone support itself. Some of the fractures must have developed before the platform was mounted. The paint residue (see Figure 10) found on fracture surfaces is one proof of this. The residue originates from painting done during construction in the Dunkerque yard. The detection of paint proves that at the fabrication stage there was a crack of at least 70mm length on the inner fillet weld. Further cracking occurred as shown in Figure 11 early in the operation of the platform.

The fractures in the joint between the hydrophone support and the bracing resulted in a stress redistribution. As a result, two diametrical points in the bracing of the hydrophone support opening were subject to higher loading than before. With the rough fracture surfaces, this initiated fatigue cracks in the bracing itself at these two points. From both points, the crack developed along the circumference of the bracing. The bracing was weakened to such an extent that it could no longer withstand the loads to which it was exposed. When the final crack occurred, about two thirds of the circumference of the bracing was split. The cracks appeared to have grown through the plate thickness of the bracing, no more than 12 months before the final crack. It is possible, however, that this final cracking developed in a substantially shorter time.

When bracing D-6 failed, the strength of the remaining five bracings supporting column D was barely sufficient to withstand still-water loading, and they collapsed shortly thereafter.

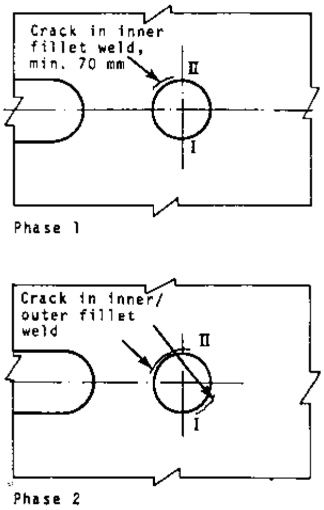
When column D was lost, the *Alexander L. Kielland* immediately heeled over to an angle of 30 to 35 degrees. Then the platform stabilized in the sea, as shown in Figure 12. From this position, it slowly continued to heel and sink, until it turned upside down about 20 minutes later.

When the platform heeled, downflooding took place at once in the trunks, column E and column C, and possibly the oblique bracings and the dry tank at the top of column E. See Figure 13. The filling of the trunks and the oblique bracings were not sufficient to overturn the *Alexander L. Kielland.* For this to happen, more than half of the deck space would have had to fill with water. If the deck had filled by flooding through open drain valves in the lower deck, the platform should not have capsized until an hour after the initial heeling. When the *Alexander L. Kielland* turned upside down after only 20 minutes, it is thought that flooding must have occurred through other openings—doors or ventilators—in the deck. However, the possibility that downflooding took place through holes caused by damage cannot be completely ruled out.

Influence of Human Management on the Cause of the Accident

The quality of the technical system, and thus a failure condition of the system, is determined by the actions, or lack of actions taken during the planning, fabrication and operation of a platform. From this point of view, the main reason for the structural failure was unfortunate design, dimensioning, and the material quality of the hydrophone support, and its connection to the bracing. Supposedly, at the planning stage, the hydrophone support was considered as outfit, not as a part of the load carrying structure. It is worth noting that no explicit evaluation of the resistance against fatigue failure or lamellar tearing was made for the actual structural component, despite the fact that the rules of Det norske Veritas contained such requirements.

Progressive collapse was not a structural design criterion in the planning of *Alexander L. Kielland.* When the platform was approved, no code for mobile units included requirements for residual strength; for instance, bracing failure. Progressive failure criteria had, however, already been introduced in certain codes for civil engineering structures.



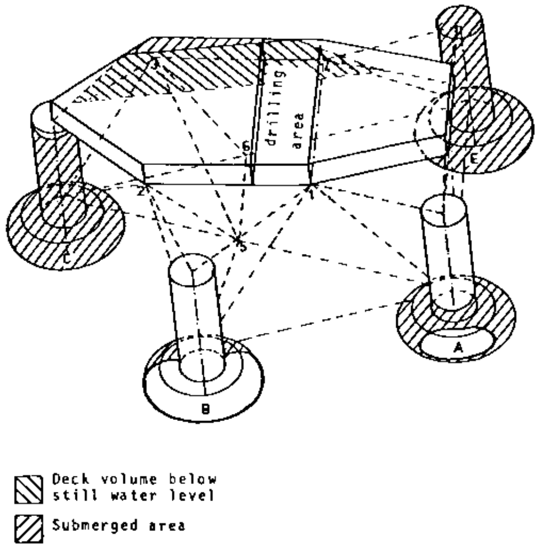


Figure 11 (left)
Probable crack development in the joint between the hydrophone support and the bracing. Phase 1. Crack proved to have occurred during fabrication. Phase 2. Probably cracks at a relatively early stage.

Figure 12
Calculated floating position of the *Alexander L. Kielland* in still water after the loss of column D.

In addition to the unfortunate design, the controls of the design were inadequate and the survey during construction and operation failed to unveil crack defects. The reason for the deficient survey was that the intentions of the regulations do not seem to have been fully carried out during the annual inspection. And to a larger extent, even an ideal survey, according to the existing rules and regulations, would not have satisfactorily controlled the actual crack defects. Both the frequency and, particularly, the extent of present practices, justify this statement. To some degree, especially in building surveys, this must be attributed to the lack of attention to the actual design detail by designers and those involved in the classification society. It might, however, be added that the Commission has no reason to believe that the conditions would have been essentially different if another classification society dealing with pentagone rigs had been responsible for the control of the *Alexander L. Kielland.*

The Commission exposes the Norwegian Maritime Directorate to scrutiny for the way it executed final responsibility for the safety control of the structure. The Maritime Directorate, in accordance with the regulations, based its approval solely on valid certification by the classification society. This practice did not give the Maritime Directorate the opportunity to double check the classification society's adherence to the rules. It should be pointed out that practices followed, in particular design control, have not been in full compliance with the Maritime Directorate's own, relatively general, regulations.

Concerning the loss of stability, the main reason the platform heeled, flooded and capsized was that the design did not anticipate the loss of a complete column (a main buoyancy member). Neither did any regulation require stability for such a circumstance at the time when the *Alexander L. Kielland* was approved.

In addition, deficient compliance with instructions for closing appliances contributed to the serious consequences of the accident. The unsecured openings rapidly filled with water in the deck. This reduced the time in which the rig remained in a position that allowed personnel to stay on board to be rescued. Instead many had to jump into the sea. The chances of surviving for more than half an hour in the cold water proved to be minimal.

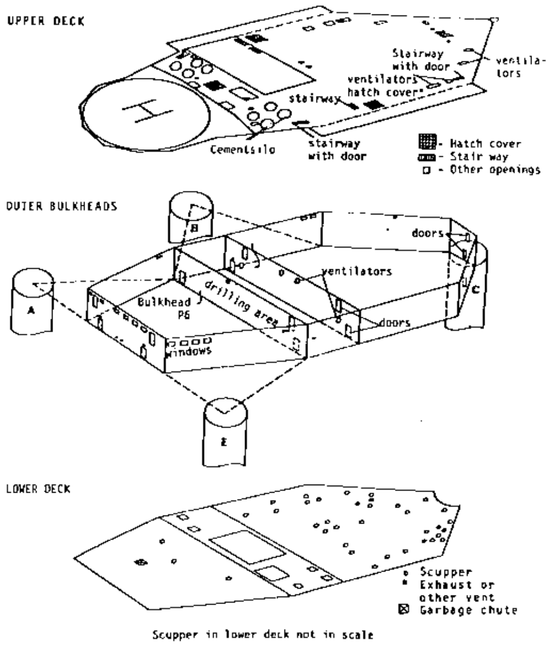


Figure 13
Openings in the outside bulkheads and decks in the *Alexander L. Kielland.*

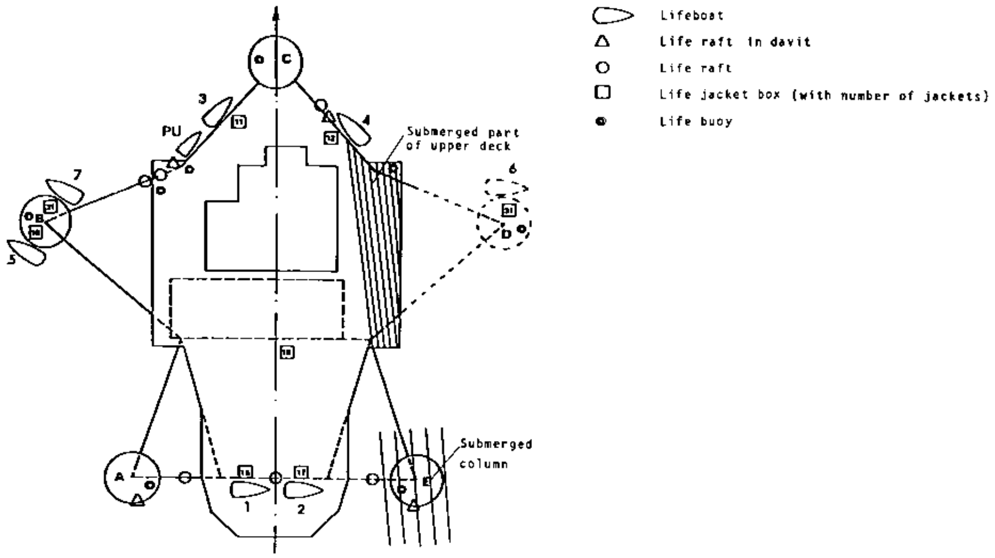


Figure 14
Lifesaving appliances on board the *Alexander L. Kielland*.

The *Alexander L. Kielland* was equipped with lifesaving appliances as required by regulations. See Figure 14. Rescue training on board was generally carried out in accordance with regulations; however, too much emphasis had been put on lifeboat practice. Only a few men on board had been given the safety training in advance, as required by regulations. Although the crew and the catering personnel on board were required to attend a three-week introductory course on safety practices, theoretical and practical, only four of the persons on board had participated in this kind of instruction. One crew member had taken a shorter, two-week safety course. Concerning the so-called "hotel guests," there are no precise requirements in the regulations regarding their safety training. However, "Arbeidsmiljoeloven" (Workers' Environment Law), which applies to employees, except for the mustered personnel, on floating platforms and fixed installations, states that all employees shall be informed about the accident and health risks. This law applied to the *Alexander L. Kielland.* Only a small number of the hotel guests had fulfilled any course and, moreover, these courses lasted essentially for one day. Of the 212 men on board the *Alexander L. Kielland* the day of the accident, only 76 persons had attended any courses. Among these, 50 persons had only been through a one-day course. Studying those who perished and those who survived, it appears that the type of training did not itself improve the chances for surviving the catastrophic circumstances of the accident. Other factors, such as experience at sea, seem to have been more important.

When the accident occurred, most people on board were on the intermediate deck. See Figure 16. About 60 were in the mess at the aft end of the platform, and 30 were in the cinema room, adjacent to the mess. About 60 men sat in the temporary cinema room amidships. Roughly 30 were in their cabins, while the rest, about 30 men, were in various places all over the rig.

The loss of column D resulted immediately in a heeling angle of about 30 to 35 degrees. The main and emergency generators stopped, leading to a total blackout. The water started to flow into the deckhouse. The people first reacted by trying to find out what had happened; then they moved toward the lifeboat stations, particularly numbers five and seven on column B, the highest point of the platform; and numbers one and two, at the aft end of the deck. Most people did not feel there was enough time to go to their cabins for life jackets or heavier clothes. Figures 15-17 show the escapeways used by the survivors.

Because the boxes of life jackets at the rescue stations were soon emptied, quite a few people were left without. Of the 89 persons who were rescued, 53 wore life jackets. Only the crew and some of the hotel guests had survival suits which were not prescribed as lifesaving equipment. Eight persons managed to put on survival suits; four of them were rescued. Four of those who perished and three of the survivors had not properly closed the zippers.

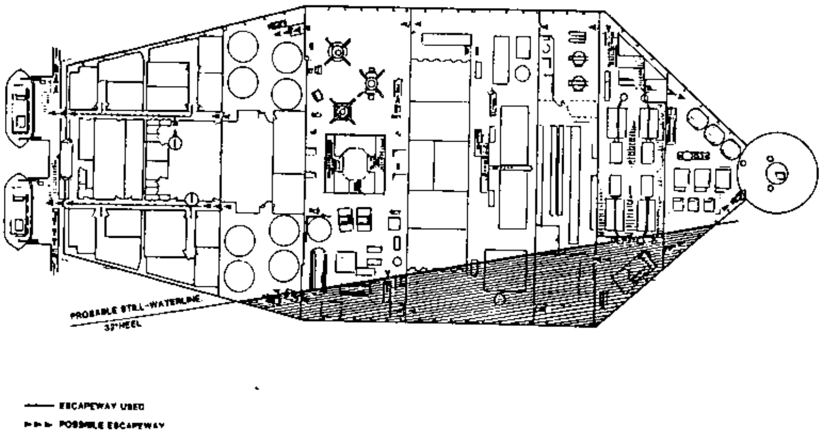


Figure 15
Escape ways on the lower deck.

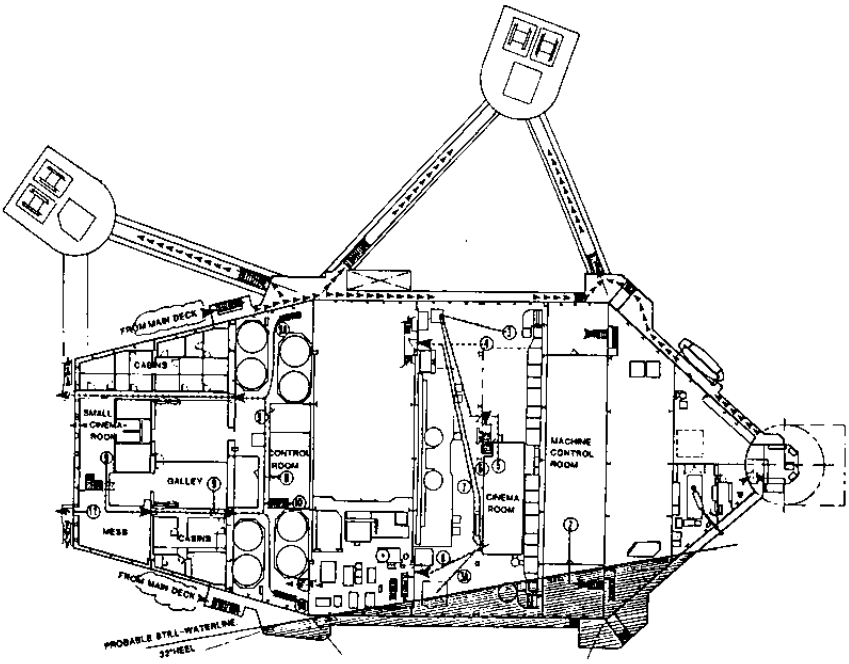


Figure 16
Escape ways on the intermediate deck.

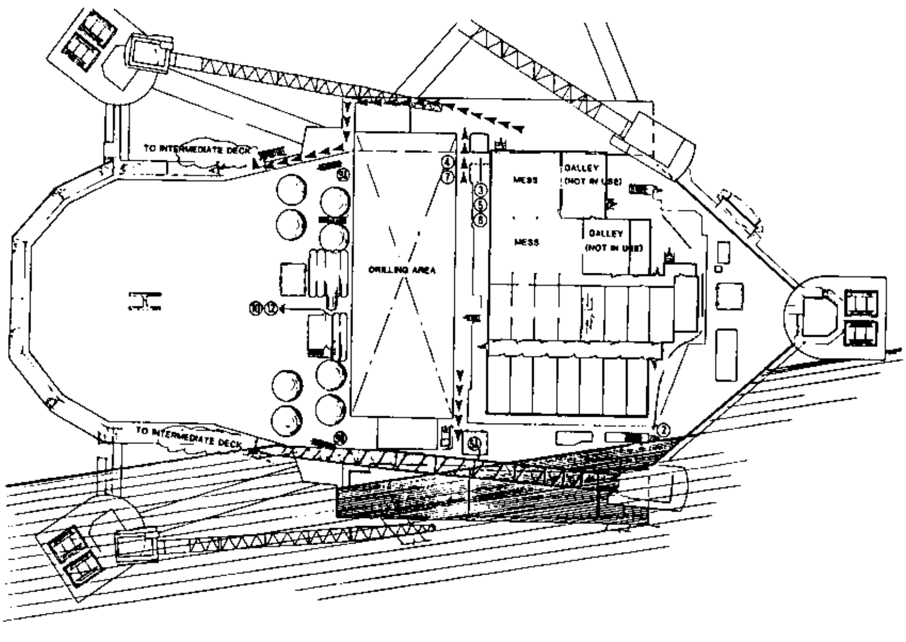


Figure 17
Escape ways on the upper deck.

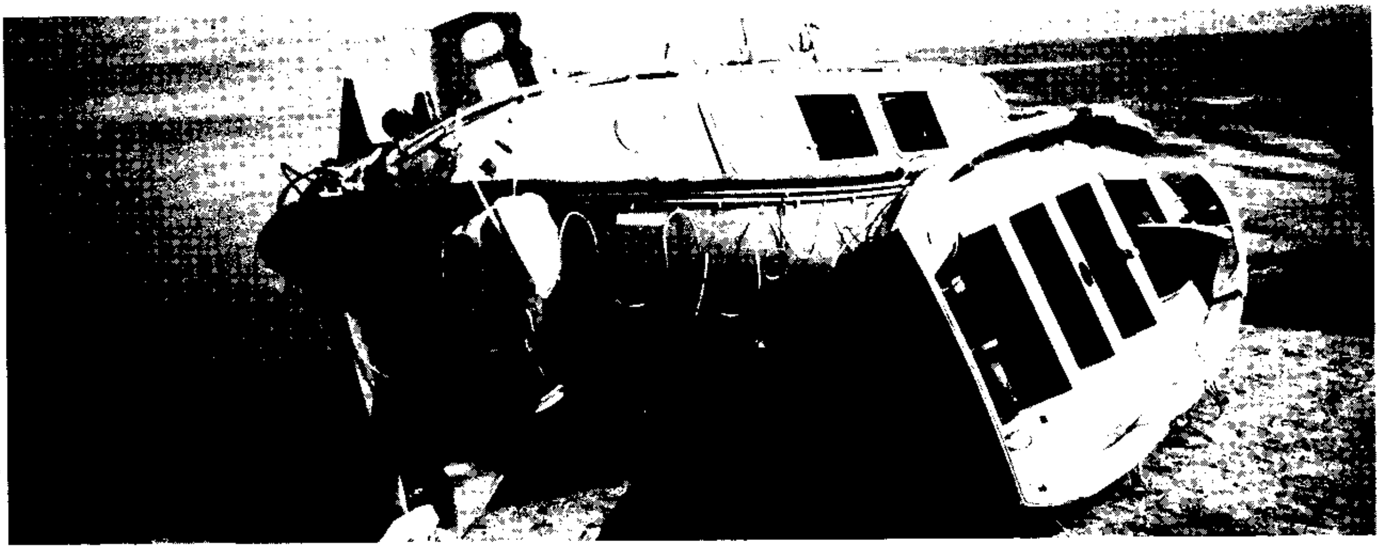


Figure 18
Lifeboat number 1 with damaged wheel house.

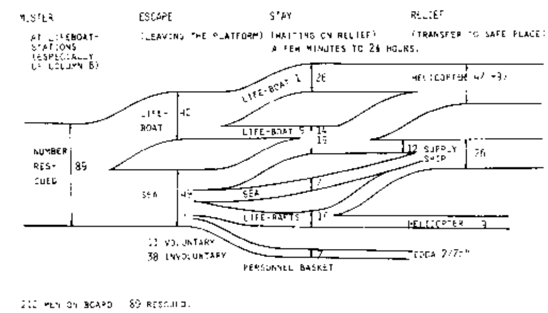


Figure 20
Summary of the evacuation and rescue operation.

On board the ***Alexander L Kielland,*** there were seven covered lifeboats, each with seats for 50 men. Four of the boats were lowered without problems. However, there were problems with the release of the lifeboat hooks. The hooks, equipped with simultaneous release mechanisms, could not be disengaged under load, a circumstance difficult to avoid because of the rough seas on the day of the accident. For this reason three of the boats were blown against the platform and damaged. On the fourth boat (noted number 1 in Figure 14 and shown in Figure 18) the afterpart of the wheelhouse was crushed. Through an opening caused by the impact, a man managed to release the aft hook by hand. Before that, someone had somehow succeeded in releasing the forward hook (noted number 5 in Figure 14 and shown in Figure 19). A fifth boat fell into the water bottom-up when the platform capsized. In some unknown way, the hooks had been released. People in the boat, and people outside it, managed by common effort to right it.

In regard to the two lifeboats which were successfully launched, 26 men on board the first were rescued by helicopter a few hours after the accident. The other boat held 14 persons when it first entered the seas. After that, 19 persons were pulled into the boat from the water. Of these, 12 men were later taken on board a supply ship, while the other 21 were rescued by helicopters. Those who were on board the lifeboats claimed they were severely chilled.

On board the ***Alexander L. Kielland*** there were inflatable rubber rafts with a total capacity to hold 400 men. The rafts were designed to be lowered by crane or thrown overboard. Unsuccessful attempts were made to release some of them. Some, however, were released as a result of the platform list. The inflatable systems on some rafts were activated when they hit the water; three men managed to board. These men were later rescued by supply vessels. Inflatable rafts were also thrown overboard from Edda 2/7C. The nine men who managed to board these were hoisted aboard a British rescue helicopter. Four men were rescued by a supply vessel from another raft from Edda 2/7C.

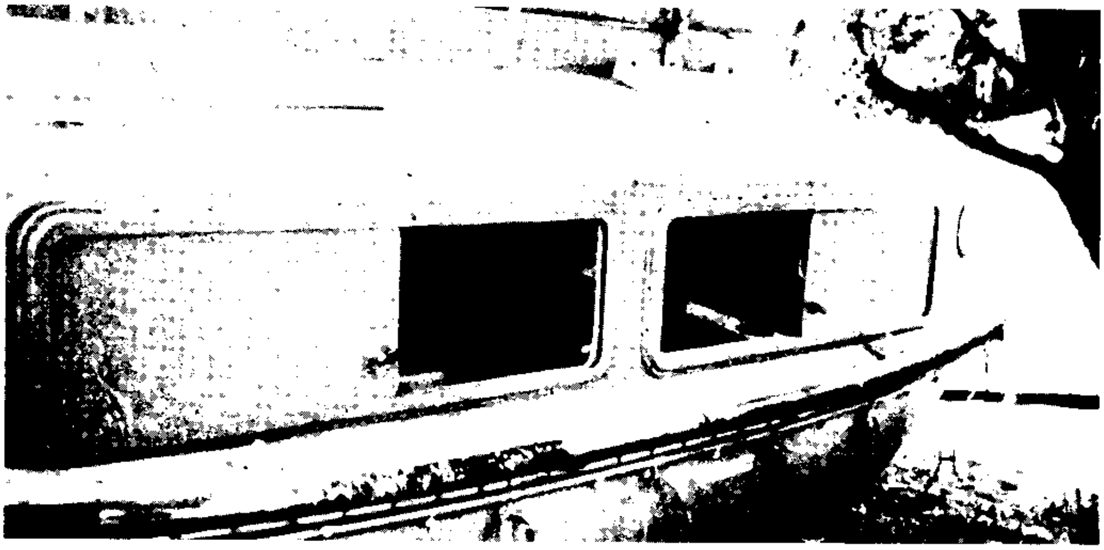


Figure 19
Starboard side of lifeboat number 5. Nineteen men were pulled from the sea and in through the open hatches.

Of all those who must have ended up in the sea when the *Alexander L. Kielland* capsized, but were not taken on board lifeboats or rafts, only 14 were rescued. Of these, seven were taken up by supply vessels, either directly from the sea or from wreckage which they clung to. Most of those who were taken from the sea were rescued within half an hour. However, one man who had put on a survival suit and a life jacket was in the sea for 2 hours and 35 minutes.

The approved emergency plan for the Ekofisk field requires that three standby vessels be placed in the area; each to be stationed in a position that allows it to reach each platform it serves within 20 to 25 minutes. The standby vessel for the *Alexander L. Kielland* did not arrive at the rig until nearly an hour after the accident. No survivors were rescued by the standby vessel.

Figure 20 summarizes the way the survivors evacuated the platform and were rescued.

A few minutes after the accident, the Rescue Coordination Center in Stavanger was alerted. The Center, working with others, applied for assistance from rescue centers abroad. They also directed vessels, many aircraft, and helicopters to the area. The search and rescue operation, all told, involved eight helicopters from Helicopter Services A-S; and eleven seeking helicoptors: three were Norwegian, four were British, two West German and two Danish. In addition, six British Nimrod and one Norwegian Orion aircraft participated in the operation. Altogether, 71 civilian vessels and nine navy vessels were engaged in the search and rescue operation. Three of the navy vessels came from Norway, three from Great Britain, two from the Netherlands and one from Denmark. As activity increased, it became difficult to maintain an overview to coordinate the air forces and the vessels in the area. Accordingly, the Rescue Coordination Center asked the British Nimrod aircraft to take command of the air traffic and a Dutch destroyer to take similar responsibilities for the ships in the area. Both the Nimrod aircraft and the destroyer performed their tasks eminently.

About an hour after the accident, the Central Hospital in Rogaland established its catastrophe office. Three-quarters of an hour later, a medical team from this office went to Sola Airport to establish a reception center for injured people. In addition, a voluntary team was flown out to Ekofisk Hotel where the team took information on those who were rescued or had perished. Those rescued were given first aid as necessary.

Altogether there were 212 men on board the *Alexander L. Kielland* when the accident happened; 123 men lost their lives.

General Items

In terms of loss of life, the *Alexander L. Kielland* catastrophe is the largest platform accident to date. The complete accident potential of platforms cannot, however, be judged on the basis of this single accident. Statistics for other systems-induced accidents, as opposed to working accidents, are presented at the end of this paper.

Based on the experiences with the *Alexander L. Kielland* and—to a certain extent—information about other accidents, the Commission presented several recommendations to improve the safety of mobile rig operations. The proposed risk-reduction actions are summarized here.

The Commission maintains that though the authorities must decide which, and to what degree, any recommendations are to be implemented, they stress the need to improve the safety level for mobile platforms. The Commission would strongly emphasize that planning actions aimed at improving the safety level should be undertaken using a general, integrated approach. This implies that the total risk spectrum, depending upon the type, function and operational mode of the platform, must be assessed by risk analysis. Hazards must be considered which may initiate structural or mooring line failure, loss of floating ability and stability, loss of electric power, et cetera; so too, must the interaction of those hazards that lead to human or economic loss. Hazards which directly may cause injury to personnel must also be included in the list of concerns.

Furthermore, risk factors relating to hardware, such as the structure and equipment, fabrication and operational procedures, and personnel must be considered. In particular, risks relating to human errors or omissions must be recognized.

A unified approach is necessary to achieve unified safety requirements within a level of risk tolerance that is acceptable to society. The unified approach recommended by the Commission has not to date been practiced to an adequate degree for mobile platforms. It should be mentioned, for example, that while requirements regarding buoyancy and stability under damaged conditions have existed for some time, there are no requirements for built-in strength for such cases.

The need for an overall approach is also supported by the fact that various safety requirements determining the layout may be in conflict with one another. The platform deck provides one such example. Requirements of load-carrying capacity, fire-resisting bulkheads, and watertight bulkheads to supply additional buoyancy suggest the need for few, small openings. On the other hand, access during evacuation would be improved by having as many large openings as possible.

An overall risk evaluation approach is particularly important when new platforms with increased size, different layout and function are planned. In the years to come, new platform technology is expected to evolve.

A complete safety evaluation should be done in the planning phase. This is the time when it would be easiest and most efficient to reduce the probability of hazards and their consequences. At the same time, approval of new platform planning should preferably take place in two parts: the concept and the detailed design stages. In this way, possible changes of the overall layout can be most easily accommodated.

On the other hand, errors and omissions in the planning phase may be difficult to identify and eliminate later, leading to hazards during construction or after the platform is in operation. Therefore, it is of the utmost importance that planning take place in organizations with management dedicated to safety and that the building be carried out by highly qualified people. In this connection, the Commission points to the general need to extend education to include systematic safety considerations based on practical experience and on results from research and development. This applies to university as well as to vocational educational level. It is particularly important to utilize experiences and analysis of all relevant factors from previous accidents. It is also necessary to arrive at better systems to exchange accident information which is sufficiently detailed.

The Commission is of the opinion that governmental authorities should have the overall responsibility for the safety of mobile units. The responsibility should include control of the planning, fabrication and operation of the platform that pertains to hull and anchoring system strength, floating ability and stability, fire resistance, and evacuation and lifesaving systems. The interaction between all these factors is of prime importance. The governmental efforts should be limited to creating the codes for safety control work and making sure they are implemented. In the opinion of the Commission, more detailed control should be delegated to other institutions, such as the classification societies. To achieve satisfactory safety control, it is necessary to involve a larger number of highly competent specialists. The availability of qualified personnel is, however, limited and will continue to be so in the years to come. For this reason, and because the classification societies already have established an organization to cover planning, fabrication and, to an increasing degree operation, only a moderate increase of the governmental apparatus for safety control seems to be necessary for mobile platforms. The safety control of mobile platforms exercised by Norwegian authorities has been based somewhat uncritically on ship design and operational experience, without fully recognizing the particulars of mobile units. At present there are greater differences between various platform concepts and between platforms and ships, than between various ship types. Continued development of platform technology is likely to bring about new concepts. The Commission is, therefore, of the opinion that the safety management of mobile units should be better organized to acknowledge the particulars of platforms and ensure adequate total control. This may be achieved by assigning particular responsibilities to certain persons, preferably organized in separate departments or groups. Besides doing safety control work, this personnel should follow up research and development work on platform systems to an increasing degree.

By considering the general items outlined above, as well as the particular recommendations with regard to strength, stability, and lifesaving appliances, there should be a reevaluation of the safety management of mobile units. In particular, rules and regulations should be established and followed up to ensure an improved safety level that is consistent among all types of platforms.

Structural Integrity of the Platform

Per definition, the structure fails when the effect of the load it is exposed to exceeds its capacity. Failure fundamentally occurs for two reasons: First, there is built-in probability that the load effect will exceed the capacity of the structure. For instance, platforms are being dimensioned today for a chosen finite level of wave loading. This means there is still a certain probability that the load will exceed the chosen value and a breakdown might result. The second major reason for failure is abnormal load, or abnormal capacity due to structural defects. Abnormal conditions can most often be traced to errors or omissions at the planning, building, or operational stage. In a few cases, however, the reason for the abnormal conditions may be truly unknown phenomena, which are not and cannot be accounted for.

It follows that various short- and long-term strategies should be used to achieve the desired safety level for mobile rig operations. The Commission has pointed to the following methods which more or less are already in use:

1
Design and dimension the structure and the anchoring system to ensure adequate safety against failure and to limit the direct consequences of the failure.

2
Plan the layout of the structure and equipment to minimize the probability of errors during construction and, particularly, operation. Make it easier to ensure better control during activities such as inspection.

3
Design the control or supervising systems for the planning, building and operational stages so that faults can be identified and eliminated.

4
Develop, transfer and utilize new knowledge and skill.

To obtain improved safety for mobile platforms it is, in the opinion of the Commission, necessary to incorporate all these planning and control strategies in the regulations, and to follow them up in practice.

The first point is the most direct and easy to implement. It should be recognized in this connection that no control system, or any effort, can completely eliminate errors and omissions that may cause abnormal loads or structural defects. The Commission, therefore, recommends that when dimensioning a structure, consideration be given to small, abnormal loads and abnormal reduction of built-in strength. At the same time, it is important to prevent small structural damage from progressing and resulting in dramatic consequences—such as the collapse or capsize of a whole structure. Design principles should take into account abnormal conditions. Special attention should be paid to establishing criteria for damage and the associated loading of damaged structures. These criteria should be compatible with those used in the evaluation of damage stability.

Further guidance should be given to the design of structural details, including welded connections, particularly when fillet welds are involved. Rules and regulations should include specifications for rational design and dimensioning of fillet welds for different kinds of connections.

The Commission recommends that wherever possible mobile platforms should be better planned for structural surveys, and with the idea they will be monitored in the future. It is also necessary to pay more attention to establishing realistic operational procedures for structural integrity.

The control of the structural safety should include the planning, construction and operational phases. The control system should primarily aim at discovering gross errors or omissions. It is recognized that control cannot be complete, but control can be made more efficient by better systematization—for instance, the use of checklists for control of the planning, and by application of inspection manuals to help check out the platform during the construction and operational phases.

The inspection manual should include information about priority of places to inspect, inspection procedures and methods to be used, as well as criteria for acceptable damage or defects. The likelihood for damage and the possible consequences of damage should be the basis for establishing such a code of practice. However, the inspection manual should be continuously updated during fabrication and operation of the actual platform and of similar types of platforms. It is presupposed that a reporting system which is suitable for the purpose will be established.

The basis for the control of the platform system planning should be the concept itself and relevant documentation, such as calculations, drawings, material specifications, building and operational procedures, as well as an inspection handbook. Total risk analysis or a similar kind of study should form the basis for evaluating the integrity of structures, particularly for new platform types. As far as possible, one should aim at independent control. The control institutions ought, therefore, to carry out independent calculations. Even if a platform has been subject to approval once, it is extremely important that it be subjected to up-to-date controls, especially if several years pass between the design and construction of a platform type. New knowledge could change the way in which the platform design should be evaluated.

Because the purpose of the inspections during construction and operation should be to uncover grave defects, the inspections should not concentrate on areas where minor damages might appear, but instead, careful study should be telescoped on a few, critical platform sections. This is not always the case at present. To ensure that latent crack formations caused during construction are released, it will be of great importance to carry out an extensive control of a new platform on the light waterline, in sheltered water, after the first complete winter it has been in continuous operation. Otherwise, main surveys carried out at two-year intervals should be sufficient. This recommendation is given by the Commission on the condition that the hull inspection be carried out with a significantly better coverage and thoroughness than has been the case up to now.

Further, more attention should be paid to devising a better system for education, training, and certification of inspectors. The control exercised by authorities during construction and operation is necessarily periodic. Between these inspections the control has to be performed by the crew on board. The content of this internal control ought to be more clearly spelled out, and followed up by attempts to improve such factors as motivation and education of the people working on the platform.

Floatability and Stability of the Platform

Loss of stability and its consequences should, in general, be counteracted by:

1
Designing platforms with adequate safety margins to withstand capsizing and flooding

2
Implementing strategies to avoid errors and omissions in planning and operation

3
Devising a control system to detect and eliminate possible faults

4
Developing, transferring, and utilizing skill.

Specifically, these recommendations suggest that damage stability criteria ought to be reevaluated. Thus, the location and extent of the initial damage or degree of waterfilling that causes a damaged or flooded condition should be established on the basis of the experiences gained from the *Alexander L. Kielland* and other accidents or near accidents. Other mobile platforms have lost a major buoyancy member and can also provide design insights.

Stability regulations should also be established to ensure that there is a realistic safety margin with respect to capsizing and progressive flooding when taking into account the uncertainties pertaining to stability calculation at the planning stage. Among other things, at present the effect of waves and the mooring system are not taken directly into account in stability control; wind moment calculations are especially uncertain; and the analysis model used to calculate flooding is simplified.

A reevaluation of damage stability criteria would lead to requirements for reserve buoyancy. For some platforms there might be a requirement for reserve buoyancy in the deck structure. In other cases, the required additional buoyancy may be provided in a different manner. The requirement should therefore be functional and non-specific. Only in this way can the design of the deck be rational and take all possible, conflicting safety requirements into account.

At the planning stage, significant efforts can be made to reduce operational errors, particularly in emergency situations. For instance, the design of the platform can include appropriate location and layout of the marine control room, location of openings, and selection and operation of closing appliances. Furthermore, more emphasis ought to be placed on realistic operational procedures and making sure the crew understands and can operate key appliances. Motivation, education and training of operational personnel using maneuvering, ballasting, and mooring operation simulators can help reduce risk. Where possible, platform design should not be based on assumptions regarding execution of emergency steps, such as closing appliances or carrying out ballast operations.

The fundamental principles for controlling the stability should be laid down in regulations. Besides, more specific guidelines regarding the practical application of the general rules would be useful. Detailed, non-mandatory guidelines for stability calculations, interpretation of damage stability criteria, location of openings, technical standards for closing appliances, and an outline of operational procedures should be included as appendices to the rules.

The control of stability at the planning stage should be based on an overall view of the platform system.

Independent control of stability calculations using computers to gain adequate accuracy should be sought.

The fulfillment of stability requirements would normally be sensitive to the location of potential downflooding openings. Therefore, particular attention should be paid to their control.

Checking procedures for emergency operations and for operational limitations related to stability, as established in the operating manual, ought to be tightened.

Even though abnormal weight conditions do not seem to have contributed to the actual accident, other information obtained by the Commission indicates that an improved system for weight control during operation should be established. This system ought to include an inclining test for any new rig and the continuous registration and reporting of weight. Spot checks by deplacement and inclining tests during operation could possibly be be useful.

Consideration should also be given to developing an improved method to make sure that operational instructions, especially for emergency situations, are known, understood, and can be applied by the maritime personnel.

Evacuation and Rescue Operations

The Commission's recommendations aim at improving the state of preparedness, both on board the platforms and for standby contingency systems.

The Commission proposes that authorities ensure that the operators in an area cooperate to ascertain appropriate standards for setting requirements. By coordinating contingency plans among various operators, it might be possible to achieve rapid, more effective assistance in emergency situations.

With regard to standby vessels, the Commission is proposing that the same arrangement should be required for all types of platforms: drilling rigs, hotel platforms, and fixed installations. The requirements should be in accordance with current rules and regulations for drilling rigs. This means that one standby vessel shall be permanently stationed for each platform at a distance of not more than one nautical mile.

The Commission further proposes that supply vessels should be equipped with lifesaving appliances so they can efficiently pick up people from the sea.

It is proposed to divide the continental shelf into helicopter rescue zones. A rescue helicopter with permanently mounted rescue hoist and a crew educated and trained for rescue operations should be located in each zone. In emergency situations, the Commission recommends that more efficient use might be made of land-based helicopters that under normal circumstances transport personnel to and from the platforms.

The Commission recommends that at least once a year a coordinated exercise should take place by activating those field rescue resources included in the contingency plan. This might be organized to include the contingency plans of several operators. The operators' onshore contingency plans should also be tested. This would include such elements as management and coordination of the operation and testing of communication lines.

The Commission's recommendations on platform lifesaving appliances partly include:

1
Extending the capacity of a few of the existing appliances

2
Improving the standard of others

3
Developing new equipment.

First, the Commission recommends a lifeboat coverage of 200 percent for all types of platforms. The proposal is in accordance with the actual requirement for fixed installations today. The need for an overcapacity of lifeboats does not seem to be less for drilling rigs and hotel platforms. For hotel platforms it seems realistic to take into account that about half the number of lifeboats may not be operative or available as a result of damage by fire, heeling, unfavorable weather conditions, or a combination of these factors. The Commission further proposes that each platform shall have 200 percent coverage of inflatable rafts for 100 persons and 100 percent coverage for the number of persons exceeding 100. For drilling rigs, this proposal in practice will not lead to any change in the inflatable raft coverage. For the two other types of platforms, (e.g., hotel platforms) the capacity of inflatable rafts will have to be increased somewhat. Taking into account the increased coverage of lifeboats, which the Commission has proposed, a launching system for inflatable rafts is considered to be unnecessary.

The only recommendations given for improvement of existing lifesaving appliances is concerned with lifeboats. In the actual accident it was the releasing mechanism of the lifeboats which failed. This releasing system will not necessarily be improved by the introduction of lifeboat hooks which can be released while under load. Experience from a previous accident shows that evacuees may panic and could release the life boat at too high a level above the sea. The Commission, therefore, recommends an intensified effort to improve releasing mechanism or to develop another launching arrangement. In the meantime, the existing equipment should be improved. For example, the cover plates fitted around the releasing hook should be strengthened to prevent the plates from bending and blocking the releasing hook. Further, the Commission proposes a number of improvements for equipment and supplies. For instance, clothing and woolen carpets should be included onboard lifeboats; the outside of the super-structure and the bottom of the boats should be fitted with reflectors.

In addition to existing lifesaving appliances, the Commission proposes that personnel baskets and survival suits be required as lifesaving appliances. The Commission proposes that each man on board shall have his own survival suit, placed in his cabin. In addition, the Commission proposes additional coverage of survival suits of 200 percent. These suits should be appropriately placed near potential escape routes and at the lifeboat stations The Commission is of the opinion that the experiences from this accident suggest that this high coverage of survival suits is necessary to ensure that every person on board a platform shall have a reasonable chance to get hold of a survival suit when rapid evacuation is necessary.

In larger dayrooms and corridors, the inventory should be fastened to the structure. Floor coverings must provide enough friction to prevent sliding. Corridors and escape ways should be equipped with separate lamps coupled to batteries which automatically engage if the main and emergency power sources fail.

Regarding qualification requirements for those who work or live on board a platform, the Commission is of the opinion that an introductory safety course should not be limited to the maritime crew and catering personnel. Other employees, and the so-called hotel guests, have at least the same need for safety training. Dispensation from the safety training course should be given only in exceptional cases.

The safety training and the exercises on board shall include the use of all lifesaving appliances on the platform. Training on board should also be extended to include testing of the evacuation procedures. When people first arrive on board a platform they should immediately be given a tour and explicitly shown the locations of all lifesaving equipment. They should also be shown the lifeboat stations to which they belong, and the evacuation route to these stations. The education and training should aim particularly at developing serious safety consciousness. Motivation of personnel should be an important part of this safety education and training.

Finally, the Commission recommends that clear guidelines for instruction be given to new personnel before they commence their duties. These guidelines should be approved by governmental authorities.

Table 1
Number of accidents for platforms in worldwide operation during 1 January 1970—31 December 1980 according to initiating event and extent of structural damage. Source: Lloyds' list

Initiating Event	Structural Loss to All Platforms[a]					Sum
	Total	Severe	Moderate	Minor	No	
Weather	7 (3)	12 (10)	30 (22)	21 (17)	9 (8)	79 (60)
Collision	4 (2)	5 (2)	17 (11)	21 (18)	23 (12)	70 (45)
Blow-out	15 (5)	13 (7)	15 (9)	14 (7)	13 (6)	70 (34)
Leakage	—	2 (2)	3 (3)	—	3 (2)	8 (7)
Machinery, etc.	1 (0)	2 (1)	5 (4)	5 (6)	—	13 (11)
Fire[b]	3 (1)	6 (2)	20 (12)	19 (12)	—	48 (27)
Explosion[b]	2 (0)	3 (2)	10 (4)	9 (6)	1 (0)	25 (12)
Out of position	—	—	3 (2)	—	6 (4)	9 (6)
Foundering	4 (1)	—	—	—	—	4 (1)
Grounding	2 (1)	6 (6)	3 (2)	5 (2)	1 (1)	17 (12)
Capsizing	11 (11)	4 (4)	3 (1)	1 (1)	—	19 (17)
Structural strength[c]	1 (1)	6 (4)	20 (14)	25 (20)	2 (2)	54 (41)
Other	2 (0)	3 (0)	1 (0)	12 (8)	15 (10)	33 (18)
Sum	52 (25)	62 (40)	130 (84)	132 (97)	73 (45)	449 (291)

[a]Mobile platforms are shown in parentheses.
[b]Fires and explosions occurring in connection with blow-outs do not belong to this category as the initiating event.
[c]This category includes structural failures that are not apparently included by rough weather or accidental loads. Hence, accidents caused by a deficient structure belong to this category.

Table 2
Number of fatal accidents occurring in connection with platforms in worldwide operation during 1 January 1970—31 December 1980 according to initiating event and extent of structural damage. Source: Lloyds' list

Initiating Event	Structural Loss to All Platforms[a]					Sum
	Total	Severe	Moderate	Minor	No	
Weather	1 (1)	—	—	—	—	1 (1)
Collision	1 (1)	1 (1)	—	1 (1)	1 (0)	4 (3)
Blow-out	4 (1)	6 (4)	2 (2)	1 (0)	—	13 (7)
Leakage	—	1 (1)	—	—	—	1 (1)
Machinery, etc.	—	—	1 (1)	—	—	1 (1)
Fire[b]	—	1 (0)	1 (0)	2 (0)	—	4 (0)
Explosion[b]	1 (0)	4 (2)	5 (2)	5 (4)	—	15 (8)
Out of position	—	—	—	—	—	—
Foundering	—	—	1 (1)	—	—	1 (1)
Grounding	—	1 (1)	—	—	—	1 (1)
Capsizing	4 (4)	3 (3)	1 (1)	—	—	8 (8)
Structural strength[c]	1 (1)	—	1 (0)	6 (4)	1 (1)	9 (6)
Other	—	—	—	4 (2)	—	4 (2)
Sum	12 (8)	17 (12)	12 (7)	19 (11)	2 (1)	62 (39)

Table 3
Number of lives lost in structural accidents for platforms in worldwide operation during 1 January 1970—31 December 1980 according to initiating event and extent of structural damage.
Source: Lloyds' list

Initiating Event	Structural Loss to All Platforms[a]					Sum
	Total	Severe	Moderate	Minor	No	
Weather	13 (13)	—	—	—	—	13 (13)
Collision	1 (1)	8 (8)	—	4 (4)	17 (0)	30 (13)
Blow-out	12 (5)	35 (26)	20 (20)	3 (0)	—	70 (51)
Leakage	—	1 (1)	—	—	—	1 (1)
Machinery, etc.	—	—	1 (1)	—	—	1 (1)
Fire[b]	—	7 (0)	2 (0)	8 (0)	—	17 (0)
Explosion[b]	4 (0)	8 (2)	11 (2)	11 (8)	—	34 (12)
Out of position	—	—	—	—	—	—
Foundering	—	—	1 (1)	—	—	1 (1)
Grounding	—	6 (6)	—	—	—	6 (6)
Capsizing	93 (93)	6 (6)	1 (1)	—	—	100 (100)
Structural strength[c]	123 (123)	—	3 (0)	10 (7)	1 (1)	137 (131)
Other	—	—	—	4 (2)	—	4 (2)
Sum	246 (235)	71 (49)	39 (25)	40 (21)	18 (1)	414 (331)

Data of systems induced accidents for the period—January 1970 to January 1981, as compiled from Lloyd's list by Det norske Veritas, are used. While the data for accidents resulting in major structural damage are extensive, the statistics for smaller accidents are incomplete because of insufficient reporting. The statistics for mobile platforms are believed to be more complete than those for fixed structures. Furthermore, the quality of the reporting system for different geographical locations varies. For these reasons the statistics should be interpreted with caution.

Table 1 shows the distribution of accidents, according to severity of the structural damage and immediate cause for all platforms including mobile ones. In Table 2 only accidents involving fatalities are categorized according to the above pattern. Table 3 shows the number of fatalities.

The statistics quoted have several implications. For instance, 10 to 15 percent of the accidents involving any kind of structural damage involve fatalities; when the damage is total or severe the percentage increases to 25 percent.

There have clearly been more major structural accidents with mobile units than with fixed platforms. Because the number of fixed platforms is roughly five times greater than the number of mobile ones, the accident rate for mobile platforms is over five times that of fixed platforms. The number of lives lost and the fatality rate have also been greater for mobile rigs than for fixed platforms.

The reason mobile platforms experience accidents more frequently than fixed platforms under operation may, among other things, be that:

1
Errors during operations—such as moving, ballasting, anchoring, which are particular for mobile rigs—represent a risk factor

2
Loss of buoyancy and stability are failure modes only associated with mobile platforms

3
The consequence of structural damage may be greater for a mobile unit because such damage can lead to flooding and consequent loss of buoyancy, as well as the direct loss of load-carrying capacity.

According to the statistics shown, one of about 100 mobile platorms experiences a major accident each year.

It should be observed that mobile units constitute a variety of structural types. The accident and fatality rates differ among these structures. The accident rate relating to severe or total structural losses is, for instance, about two to four times greater for jack-ups than for semi-submersibles. However, fatality rates do not differ significantly between these two types of platforms.

As far as the initiation of accidents is concerned, Table 1 indicates that weather—and, as it turns out to be in many cases, maloperation—are important factors for mobile units. Collisions, blow-outs, fire and inadequate structural strength also frequently result in accidents. Most accidents on fixed platforms are caused by blow-outs, fires, collisions, and weather.

Tables 2 and 3 show that most fatal accidents pertaining to mobile platforms are caused by blow-outs, explosions, capsizing and inadequate strength. It is noted that two categories, capsizing and inadequate structure, accounted for 60 percent of the fatalities. Most fatal accidents in connection with fixed platforms have been induced by blow-outs and explosions. The accidents which have caused most fatalities are due to blow-outs, explosions, and collisions.

This lecture was based on the *Alexander L. Kielland - Ulykken Report* by the Commission set up by the Norwegian Government by a Royal Decree of March 28, 1980, Report NOU 1981:11, Oslo, March 1981 (in Norwegian with a summary in English).